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(54) **DISPLAY APPARATUS AND METHOD OF MANUFACTURING THE SAME**

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H01L 51/52	(2006.01)
H01L 51/50	(2006.01)

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(58) **Field of Classification Search**

CPC H01L 51/5237; H01L 51/5271; H01L 27/322

See application file for complete search history.

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(57) **ABSTRACT**

A display apparatus includes a first substrate; a first light-emitting device, a second light-emitting device, and a third light-emitting device disposed over the first substrate, each of the first to third light-emitting devices including a first light emission layer; a second substrate disposed over the first substrate with the first to third light-emitting devices therebetween, the second substrate including a first through hole, a second through hole, and a third through hole overlapping the first to third light-emitting devices; a reflective layer on an inner surface of each of the first to third through holes; a first color filter layer in the first through hole; a second color filter layer and a second quantum dot layer in the second through hole; and a third color filter layer and a third quantum dot layer in the third through hole.

16 Claims, 11 Drawing Sheets

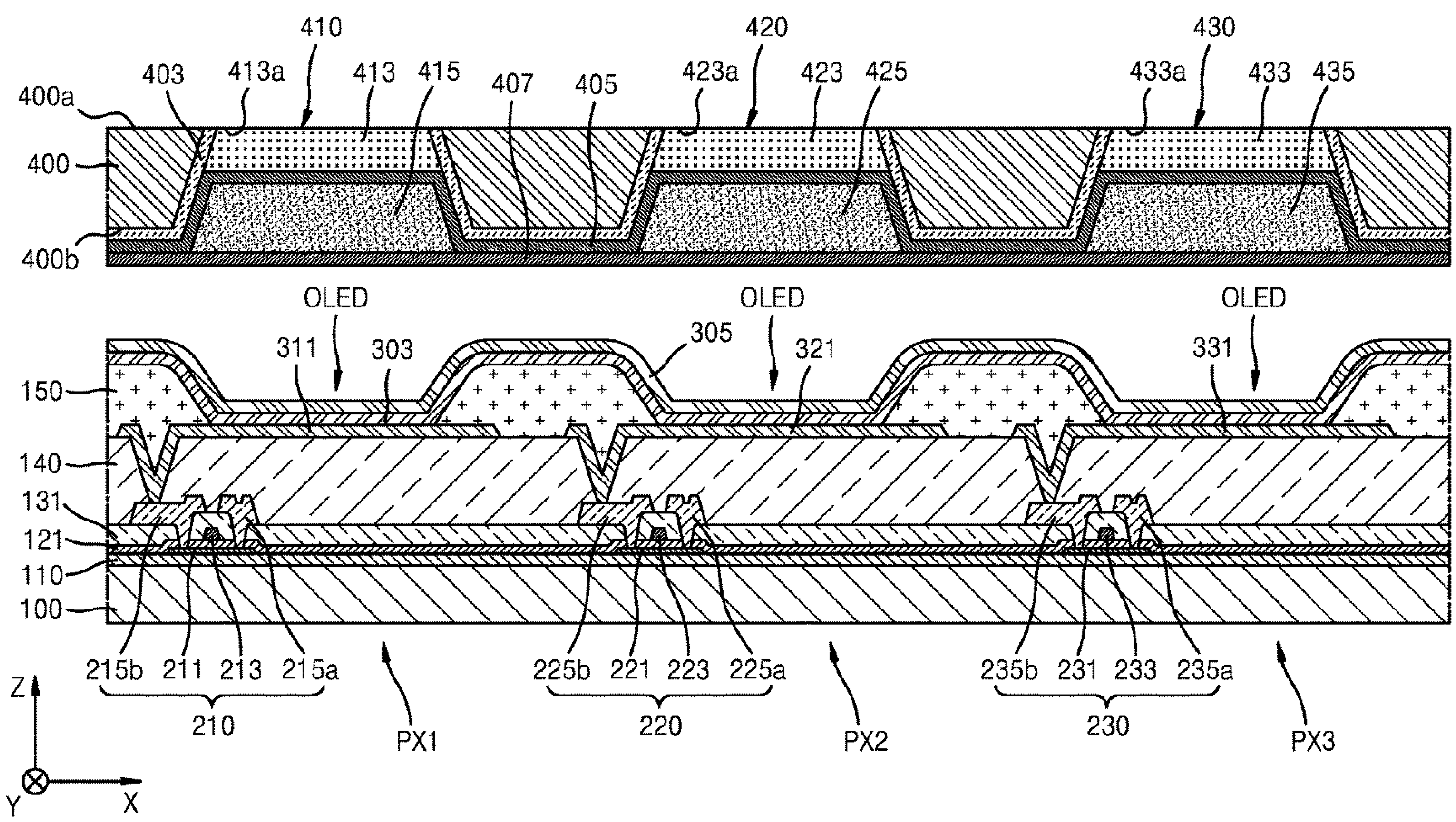

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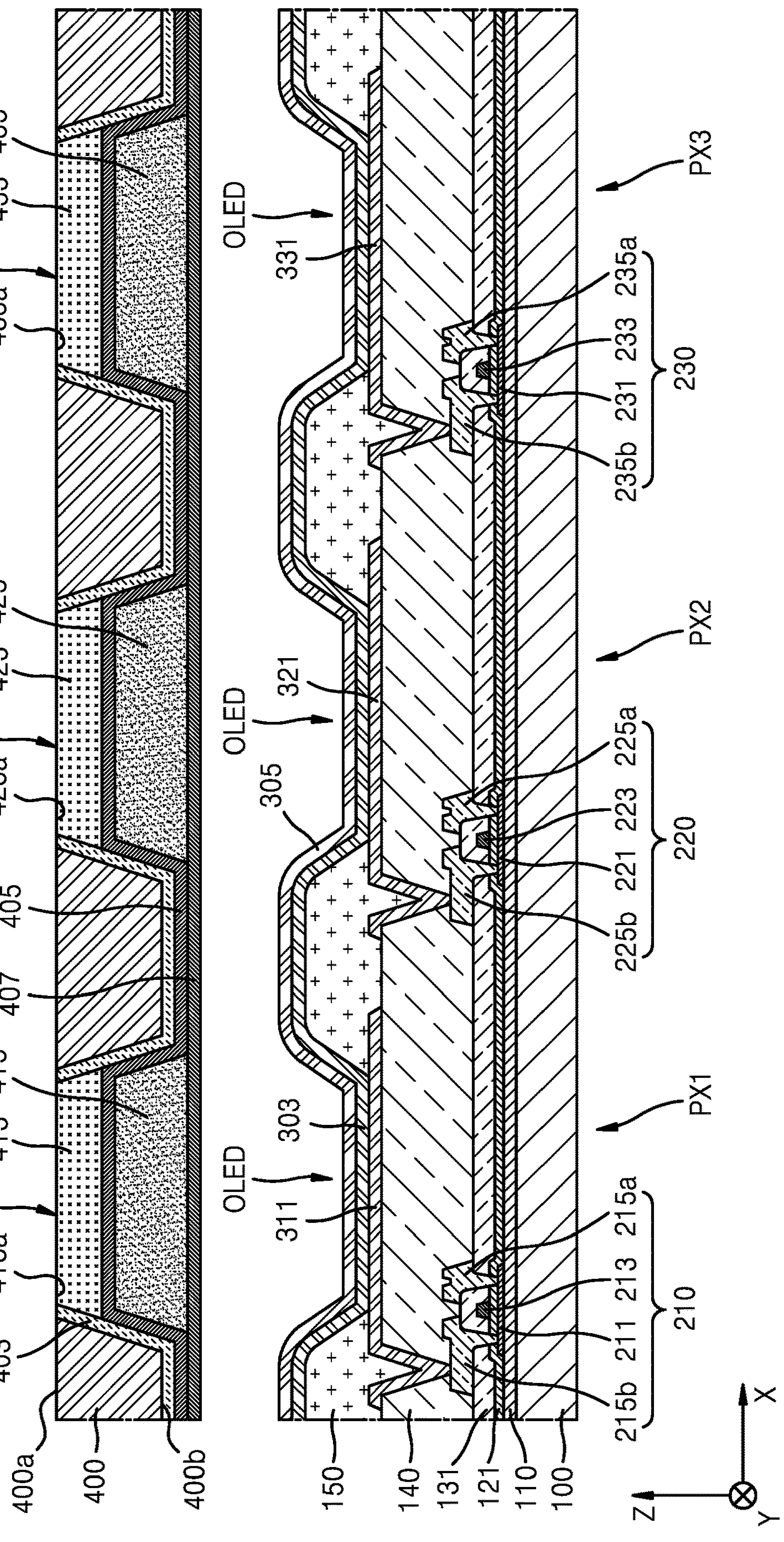
FIG. 1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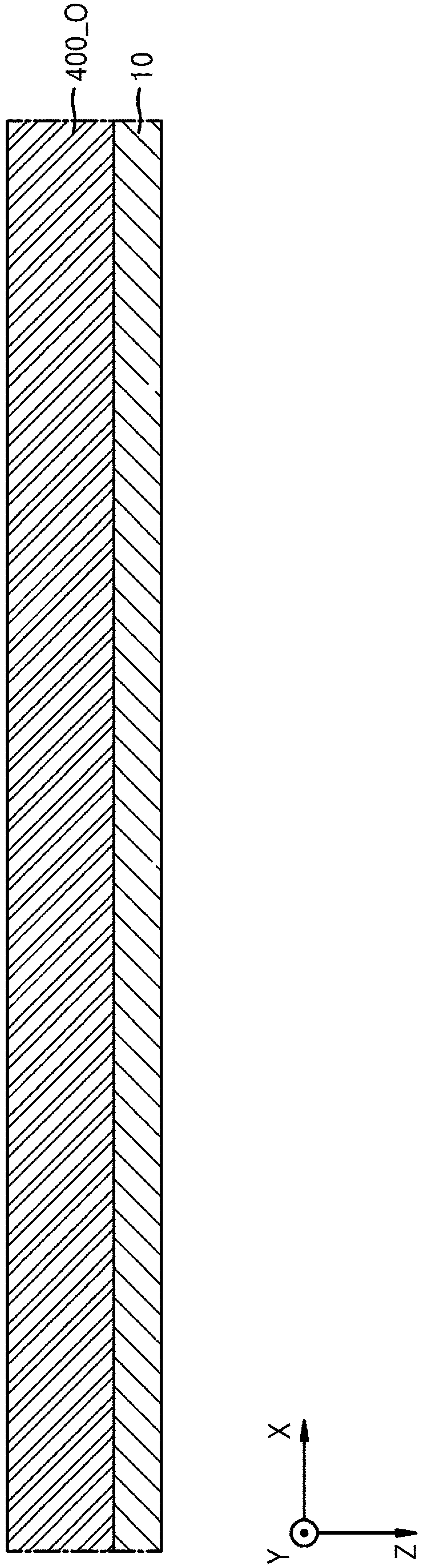

FIG. 2A

FIG. 2B

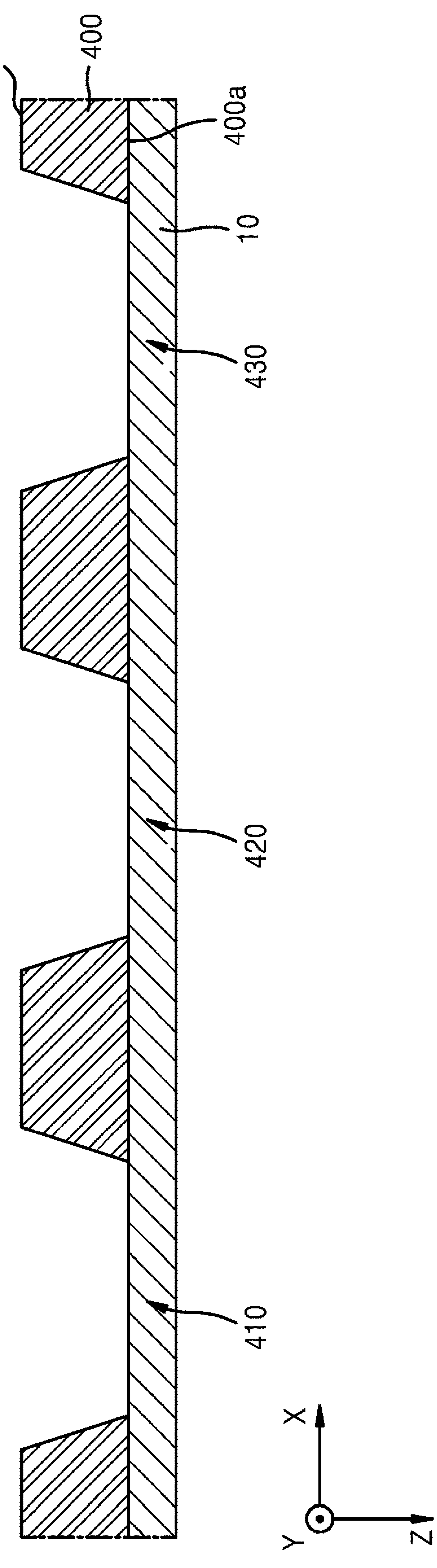

FIG. 3

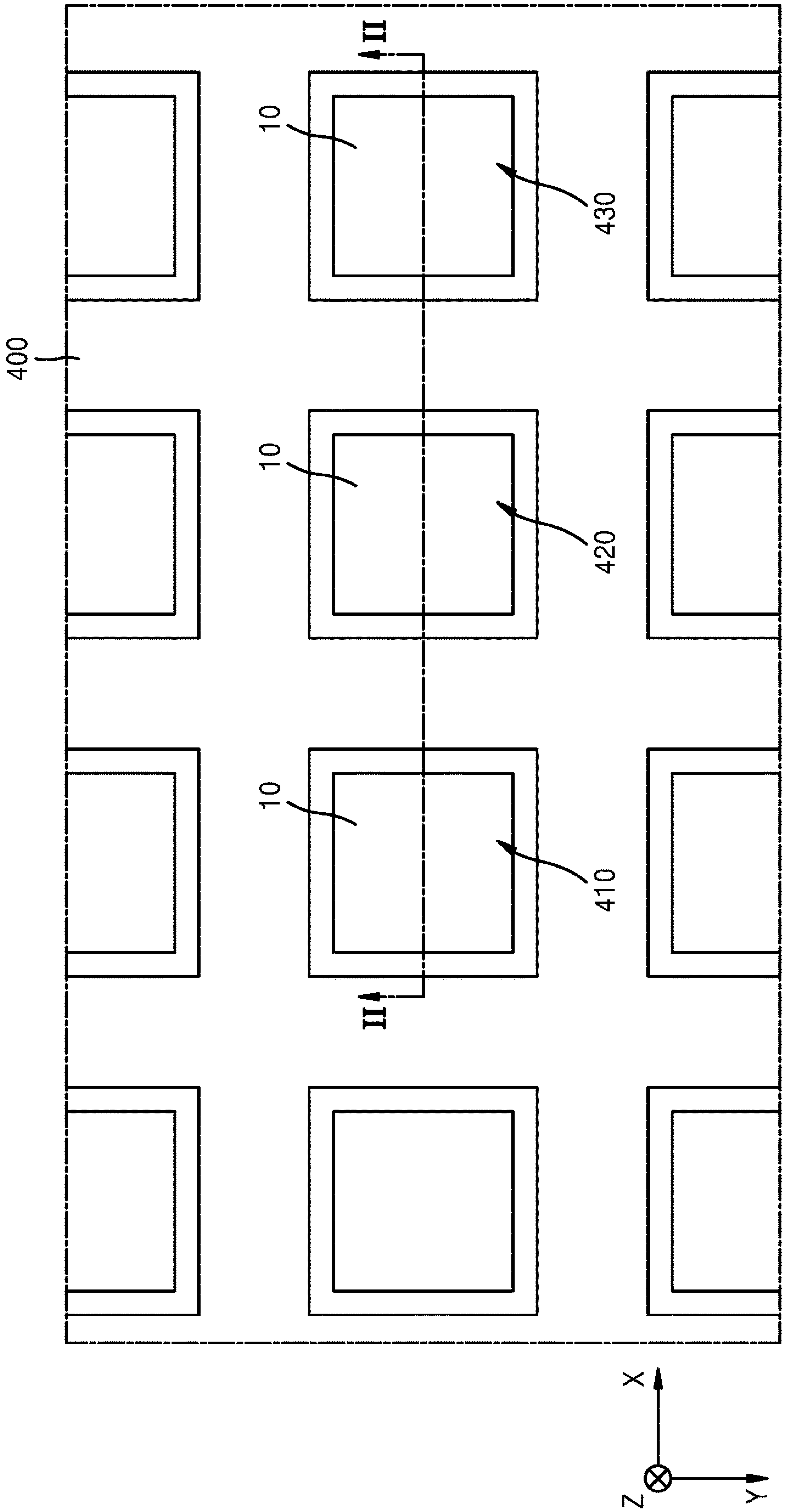

FIG. 4

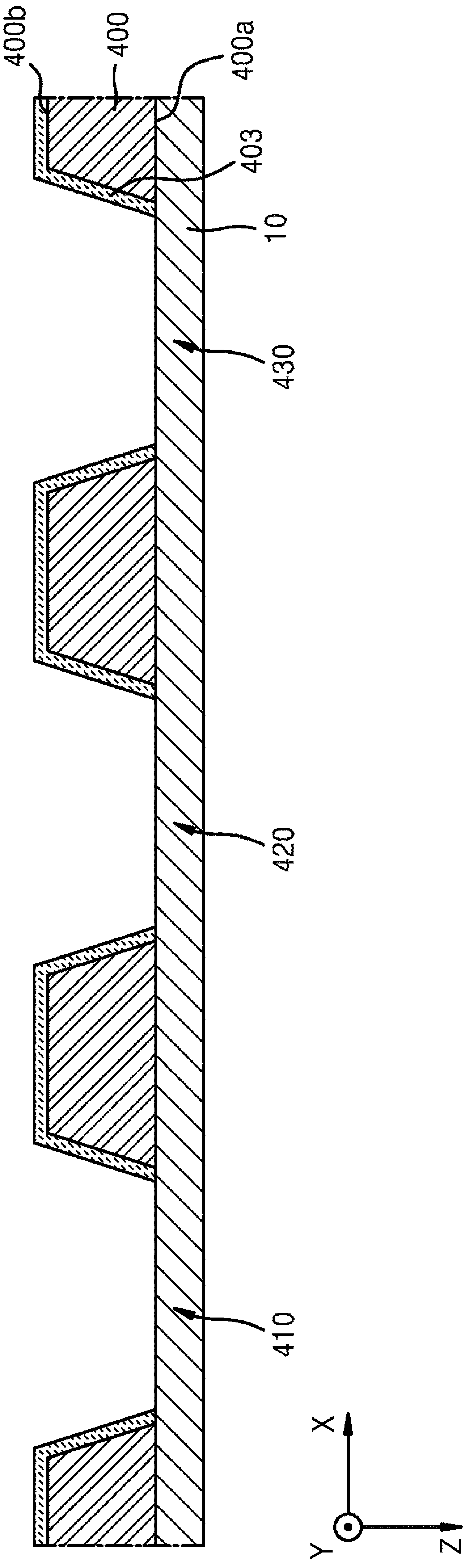

FIG. 5

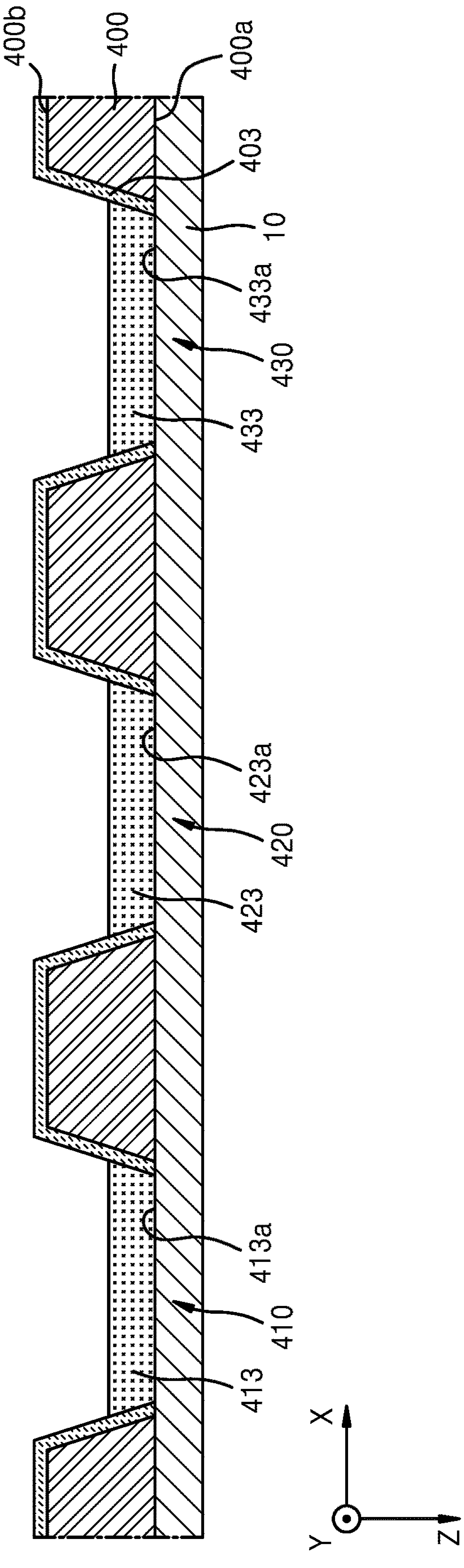

FIG. 6

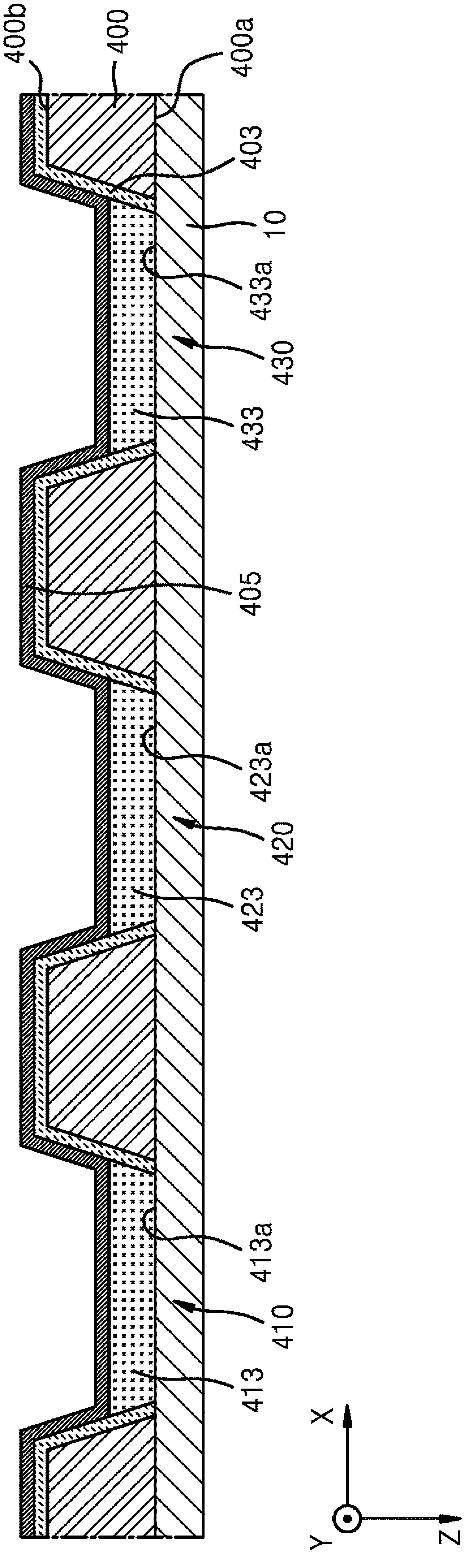
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FIG. 7

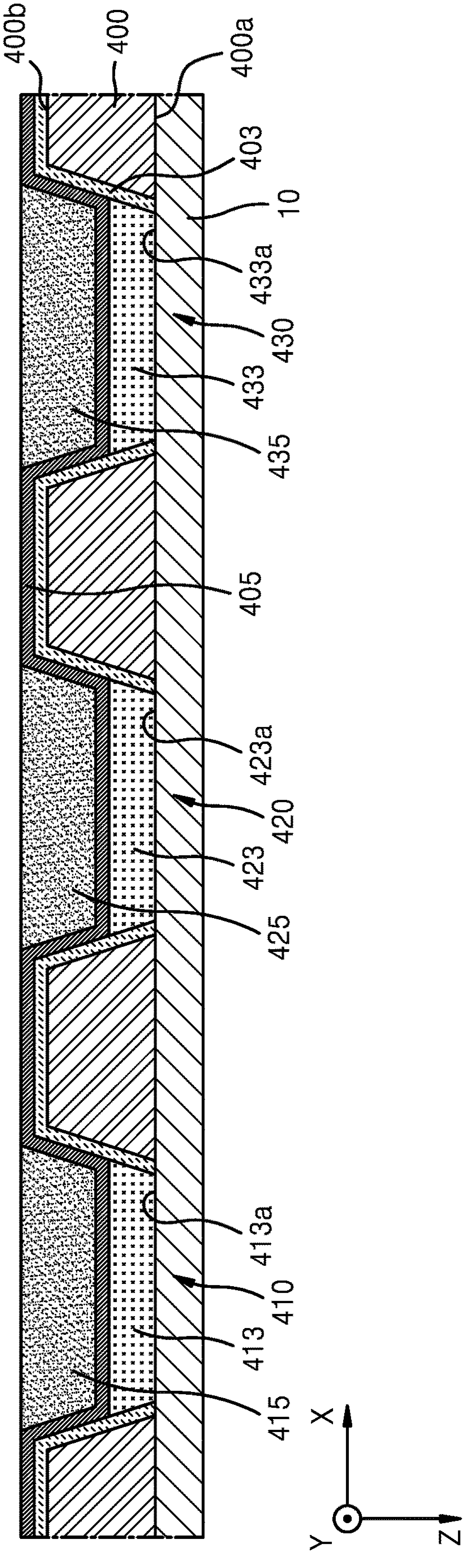
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FIG. 8

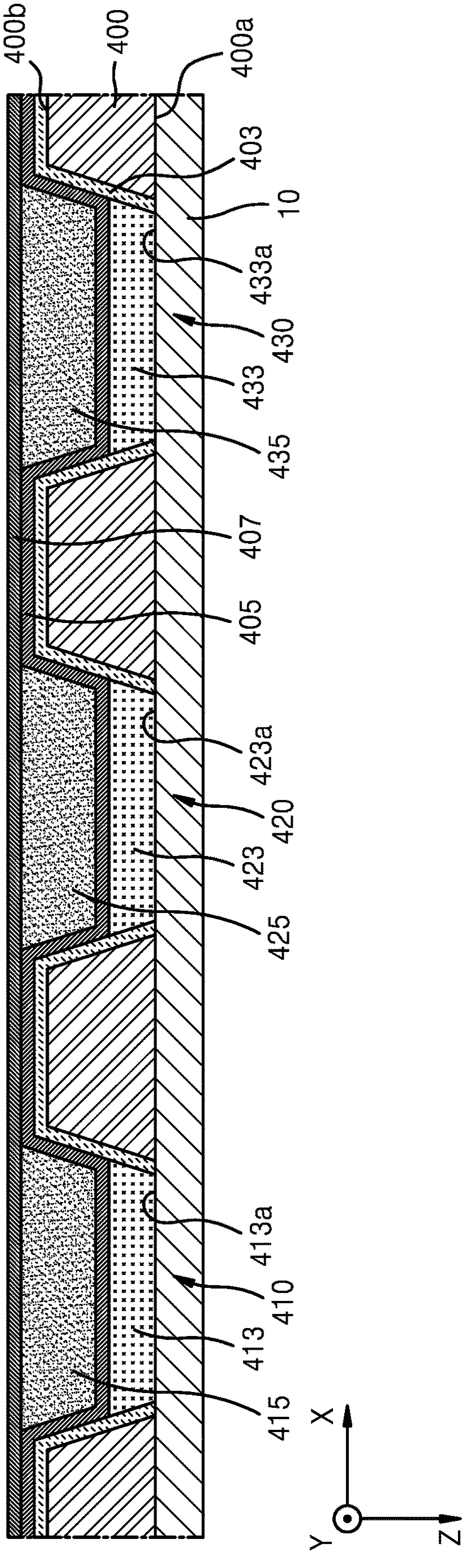
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FIG. 9

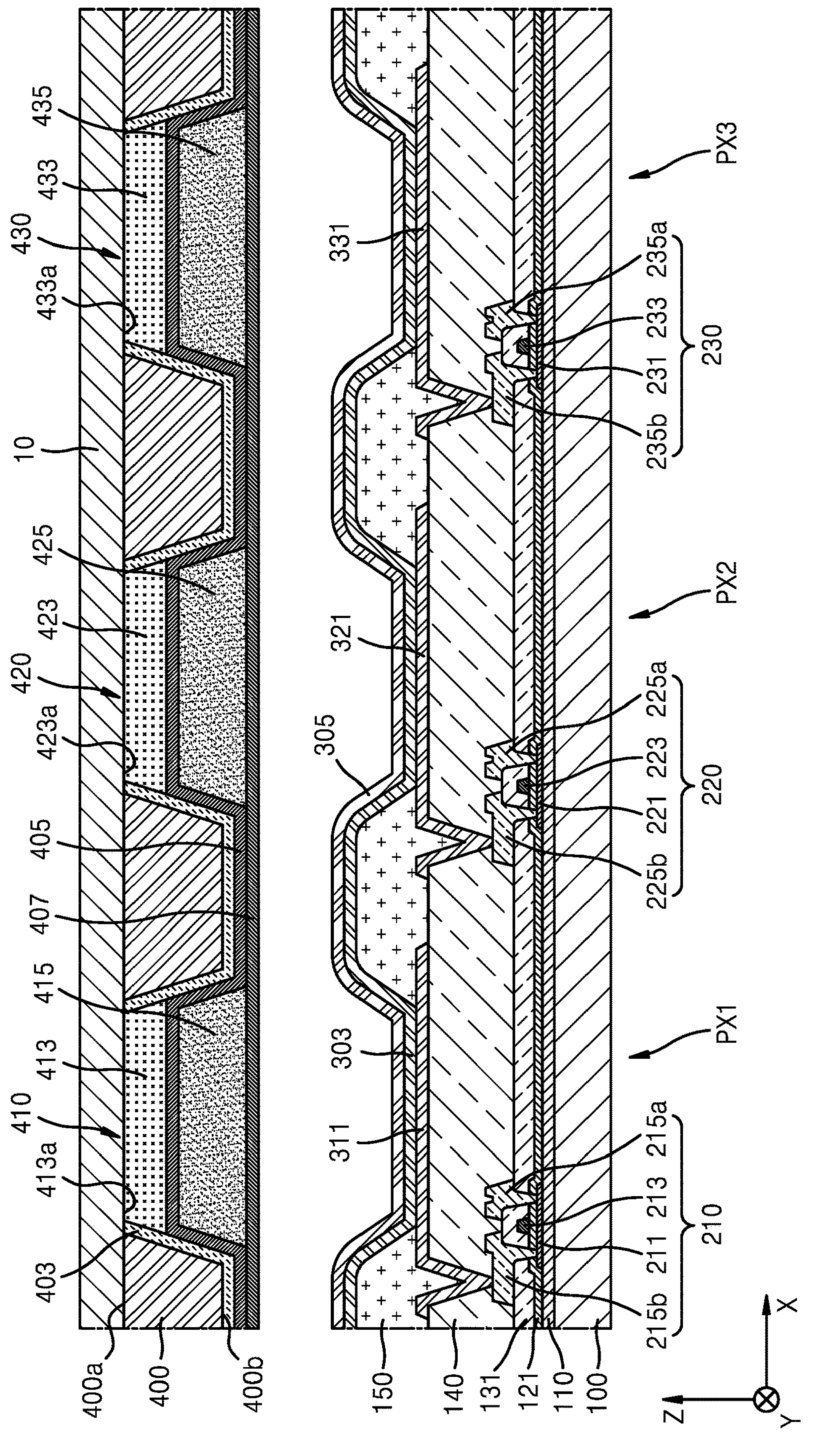
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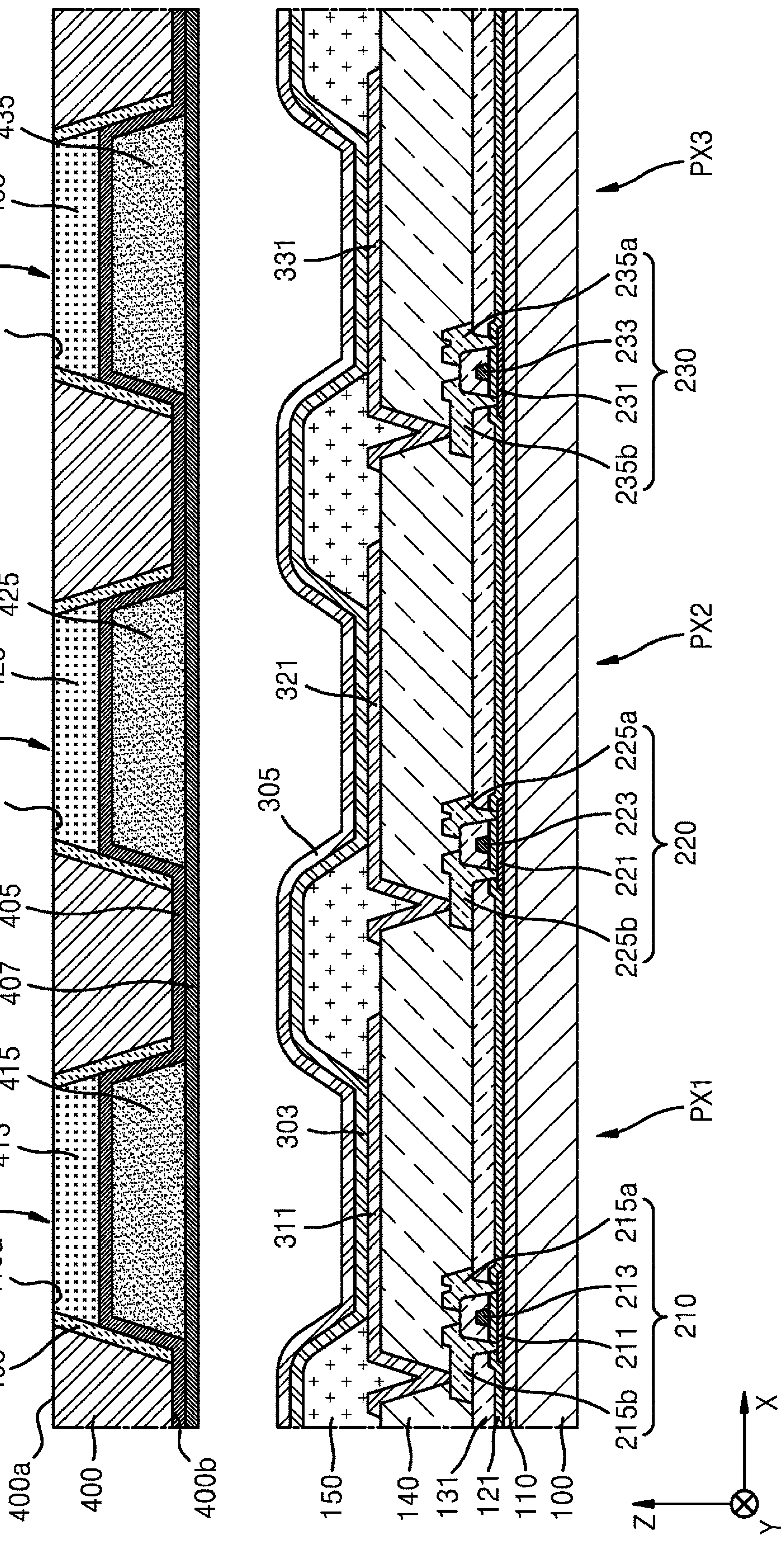
FIG. 10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DISPLAY APPARATUS AND METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from and the benefit of Korean Patent Application No. 10-2020-0030758, filed on Mar. 12, 2020, which is hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND

Field

Exemplary implementations of the invention relate generally to a display apparatus and a method of manufacturing the same, and more specifically, to a display apparatus and a method of manufacturing the same for reducing the defect ratio of the display apparatus and the amount of consumed material during manufacturing.

Discussion of the Background

A display apparatus includes a plurality of pixels. The plurality of pixels may emit different colors of light for implementing a full-color display apparatus. To this end, at least some pixels of the display apparatus each have a color conversion unit. Accordingly, first color light generated from a light-emitting portion of some pixels is converted into second color light while passing through a corresponding color conversion unit, and then the second color light is emitted to the outside.

The above information disclosed in this Background section is only for understanding of the background of the inventive concepts, and, therefore, it may contain information that does not constitute prior art.

SUMMARY

Applicant discovered that an excessive amount of a material for forming a color conversion unit of a display apparatus may be used and a high defect ratio of the display apparatus is caused during the manufacturing processes forming the color conversion unit.

Display apparatuses with color filters and color conversion units constructed according to the principles and exemplary implementations of the invention and methods of fabricating the same according to the principles of the invention are capable of guaranteeing a low defect ratio and reducing the amount of a material consumed during manufacturing processes. For example, these benefits may be achieved by forming the color filter and color conversion units in through holes of a separate upper substrate, which is subsequently joined to a lower substrate containing the display panel and light emitting elements.

Additional features of the inventive concepts will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the inventive concepts.

According to an aspect of the invention, a display apparatus includes: a first substrate; a first light-emitting device, a second light-emitting device, and a third light-emitting device disposed over the first substrate, each of the first to third light-emitting devices including a first light emission layer; a second substrate disposed over the first substrate with the first to third light-emitting devices therebetween, the second substrate including a first through hole, a second through hole, and a third through hole overlapping the first to third light-emitting devices; a reflective layer on an inner surface of each of the first to third through holes; a first color filter layer in the first through hole; a second color filter layer and a second quantum dot layer in the second through hole; and a third color filter layer and a third quantum dot layer in the third through hole.

The first to third light-emitting devices may include a first pixel electrode, a second pixel electrode, and a third pixel electrode; and an opposite electrode overlapping the first to third pixel electrodes, wherein the first light emission layer may be disposed over the first to third pixel electrodes and interposed between the first to third pixel electrodes and the opposite electrode.

The first light emission layer may be configured to emit light in a first wavelength band, the second quantum dot layer may be configured to convert the light in the first wavelength band into light in a second wavelength band, and the third quantum dot layer may be configured to convert the light in the first wavelength band into light in a third wavelength band.

The reflective layer may cover a portion of a first surface of the second substrate outside the first to third through holes, the first surface of the second substrate facing the first substrate.

The second quantum dot layer may be between the second color filter layer and the second light-emitting device, and the third quantum dot layer may be between the third color filter layer and the third light-emitting device.

The first substrate may be a lower substrate, the second substrate may be an upper substrate, and an upper surface of the first color filter layer, an upper surface of the second color filter layer, and an upper surface of the third color filter layer, may form a substantially continuous surface with an upper surface of the upper substrate, the upper surface of the upper substrate opposite to the lower substrate.

The display apparatus may include a first protective layer between the second color filter layer and the second quantum dot layer and between the third color filter layer and the third quantum dot layer.

The first protective layer may be integrally formed as a single body over an entire surface of the second substrate.

The display apparatus may include a light transmission layer in the first through hole interposed between the first color filter layer and the first light-emitting device.

The first protective layer may be between the first color filter layer and the light transmission layer.

The display apparatus may include a second protective layer between the second quantum dot layer and the second light-emitting device and between the third quantum dot layer and the third light-emitting device.

The second protective layer may be integrally formed as a single body over substantially an entire surface of the second substrate.

The second protective layer may be in contact with the first protective layer on a portion of a lower surface of the second substrate outside the first to third through holes, the lower surface facing the first substrate.

The inner surface of each of the first to third through holes may be inclined with respect to a first surface of the second substrate, the first surface facing the first substrate.

A first cross-sectional area of each of the first to third through holes taken along a first plane substantially parallel to a first surface of the second substrate may be smaller than a second cross-sectional area of each of the first to third through holes taken along a second plane substantially parallel to the first surface of the second substrate, the second plane being closer to the first substrate than the first plane, the first surface facing the first substrate.

The second substrate may include an opaque material.

The second substrate may include a black pigment.

The second substrate may be opaque.

According to another aspect of the invention, a method of manufacturing a display apparatus includes the steps: forming a layer of a first substrate on a carrier substrate; forming the first substrate by forming a first through hole, a second through hole, and a third through hole in the layer of the first substrate; forming a reflective layer on the first substrate; removing the reflective layer on the carrier substrate in the first to third through holes; forming a first color filter layer in the first through hole; forming a second color filter layer in the second through hole; forming a third color filter layer in the third through hole; forming a first quantum dot layer on the second color filter layer in the second through hole; and forming a second quantum dot layer on the third color filter layer in the third through hole.

The method may further include the steps of: forming a first light-emitting device, a second light-emitting device, and a third light-emitting device over a second substrate, the first to third light-emitting devices including a first light emission layer; and aligning and bonding the first substrate and the second substrate to each other with the first to third light-emitting devices therebetween, wherein the first to third through holes may overlap the first to third light-emitting devices.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate exemplary embodiments of the invention, and together with the description serve to explain the inventive concepts.

FIG. **1** is a cross-sectional view of an exemplary embodiment of a display apparatus constructed according to the principles of the invention.

FIGS. **2**A to **9** are cross-sectional views or plan views illustrating processes of manufacturing the display apparatus of FIG. **1**.

FIG. **10** is a cross-sectional view of another exemplary embodiment of the display apparatus constructed according to the principles of the invention.

DETAILED DESCRIPTION

In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of various exemplary embodiments or implementations of the invention. As used herein "embodiments" and "implementations" are interchangeable words that are non-limiting examples of devices or methods employing one or more of the inventive concepts disclosed herein. It is apparent, however, that various exemplary embodiments may be practiced without these specific details or with one or more equivalent arrangements. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring various exemplary embodiments. Further, various exemplary embodiments may be different, but do not have to be exclusive. For example, specific shapes, configurations, and characteristics of an exemplary embodiment may be used or implemented in another exemplary embodiment without departing from the inventive concepts.

Unless otherwise specified, the illustrated exemplary embodiments are to be understood as providing exemplary features of varying detail of some ways in which the inventive concepts may be implemented in practice. Therefore, unless otherwise specified, the features, components, modules, layers, films, panels, regions, and/or aspects, etc. (hereinafter individually or collectively referred to as "elements"), of the various embodiments may be otherwise combined, separated, interchanged, and/or rearranged without departing from the inventive concepts.

The use of cross-hatching and/or shading in the accompanying drawings is generally provided to clarify boundaries between adjacent elements. As such, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, dimensions, proportions, commonalities between illustrated elements, and/or any other characteristic, attribute, property, etc., of the elements, unless specified. Further, in the accompanying drawings, the size and relative sizes of elements may be exaggerated for clarity and/or descriptive purposes. When an exemplary embodiment may be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order. Also, like reference numerals denote like elements.

When an element, such as a layer, is referred to as being "on," "connected to," or "coupled to" another element or layer, it may be directly on, connected to, or coupled to the other element or layer or intervening elements or layers may be present. When, however, an element or layer is referred to as being "directly on," "directly connected to," or "directly coupled to" another element or layer, there are no intervening elements or layers present. To this end, the term "connected" may refer to physical, electrical, and/or fluid connection, with or without intervening elements. Further, the D1-axis, the D2-axis, and the D3-axis are not limited to three axes of a rectangular coordinate system, such as the x, y, and z-axes, and may be interpreted in a broader sense. For example, the D1-axis, the D2-axis, and the D3-axis may be perpendicular to one another, or may represent different directions that are not perpendicular to one another. For the purposes of this disclosure, "at least one of X, Y, and Z" and "at least one selected from the group consisting of X, Y, and Z" may be construed as X only, Y only, Z only, or any combination of two or more of X, Y, and Z, such as, for instance, XYZ, XYY, YZ, and ZZ. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

Although the terms "first," "second," etc. may be used herein to describe various types of elements, these elements should not be limited by these terms. These terms are used to distinguish one element from another element. Thus, a first element discussed below could be termed a second element without departing from the teachings of the disclosure.

Spatially relative terms, such as "beneath," "below," "under," "lower," "above," "upper," "over," "higher," "side" (e.g., as in "sidewall"), and the like, may be used herein for descriptive purposes, and, thereby, to describe one elements relationship to another element(s) as illustrated in the drawings. Spatially relative terms are intended to encompass different orientations of an apparatus in use, operation, and/or manufacture in addition to the orientation depicted in the drawings. For example, if the apparatus in the drawings is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the exemplary term "below" can encompass both an orientation of above and below. Furthermore, the apparatus may be otherwise oriented (e.g., rotated 90 degrees or at other orientations), and, as such, the spatially relative descriptors used herein are interpreted accordingly.

The terminology used herein is for the purpose of describing particular embodiments and is not intended to be limiting. As used herein, the singular forms, "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. Moreover, the terms "comprises," "comprising," "includes," and/or "including," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. It is also noted that, as used herein, the terms "substantially," "about," and other similar terms, are used as terms of approximation and not as terms of degree, and, as such, are utilized to account for inherent deviations in measured, calculated, and/or provided values that would be recognized by one of ordinary skill in the art.

Various exemplary embodiments are described herein with reference to sectional and/or exploded illustrations that are schematic illustrations of idealized exemplary embodiments and/or intermediate structures. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, exemplary embodiments disclosed herein should not necessarily be construed as limited to the particular illustrated shapes of regions, but are to include deviations in shapes that result from, for instance, manufacturing. In this manner, regions illustrated in the drawings may be schematic in nature and the shapes of these regions may not reflect actual shapes of regions of a device and, as such, are not necessarily intended to be limiting.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure is a part. Terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and should not be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

FIG. **1** is a cross-sectional view of an exemplary embodiment of a display apparatus constructed according to the principles of the invention. As shown in FIG. **1**, the display apparatus includes first to third pixels PX**1** to PX**3**. However, the display apparatus may include more pixels. In FIG. **1**, the first to third pixels PX**1** to PX**3** are adjacent to one another, but one or more exemplary embodiments are not limited thereto. For example, other elements such as wirings may be among the first to third pixels PX**1** to PX**3**. Accordingly, the first and second pixels PX**1** and PX**2**, for example, may not be adjacent to each other. Also, in FIG. **1**, cross-sections of the first to third pixels PX**1** to PX**3** may not be taken along the same direction.

The display apparatus includes a lower substrate **100**. The lower substrate **100** may include glass, metal, a polymer resin, or the like. When the lower substrate **100** is flexible or bendable, the lower substrate **100** may include a polymer resin such as a polyethersulfone, polyacrylate, polyetherimide, polyethylene naphthalate, polyethylene terephthalate, polyphynylene sulfide, polyarylate, polyimide, polycarbonate, or cellulose acetate propionate. The lower substrate **100** may be variously modified, for example, the lower substrate **100** may have a multi-layered structure including at least two layers and a barrier layer between the at least two layers. Each of the at least two layers may include a polymer resin, and the barrier layer may include an inorganic material such as silicon oxide, silicon nitride, silicon oxynitride, or the like.

A first pixel electrode **311**, a second pixel electrode **321**, and a third pixel electrode **331** are disposed on the lower substrate **100**. For example, a plurality of display devices is disposed on the lower substrate **100**. In addition to the display devices, first to third thin film transistors **210**, **220**, and **230** electrically connected to the display devices may be on the lower substrate **100**. In FIG. **1**, the display devices are in the form of organic light-emitting devices disposed on the lower substrate **100** but any type of light-emitting devices suitable for use as display devices in a display panel may be employed in exemplary embodiments of the invention. The organic light-emitting devices are electrically connected to the first to third thin film transistors **210**, **220**, and **230** through the first to third pixel electrodes **311**, **321**, and **331**.

In FIG. **1**, the first thin film transistor **210** is in the first pixel PX**1**, the second thin film transistor **220** is in the second pixel PX**2**, and the third thin film transistor **230** is in the third pixel PX**3**. In addition, the first to third thin film transistors **210** to **230** are respectively connected to the pixel electrodes of the display devices in the corresponding pixels. Hereinafter, the first thin film transistor **210** and the display device connected to the first thin film transistor **210** will be described for convenience of description, and the description may be also applied to the second and third thin film transistors **220** and **230** and the display devices connected to the second and third thin film transistors **220** and **230**. That is, descriptions of a second semiconductor layer **221**, a second gate electrode **223**, a second source electrode **225***a*, and a second drain electrode **225***b* of the second thin film transistor **220**, and the second pixel electrode **321** are omitted to avoid redundancy. Likewise, descriptions of a third semiconductor layer **231**, a third gate electrode **233**, a third source electrode **235***a*, and a third drain electrode **235***b* of the third thin film transistor **230**, and the third pixel electrode **331** are omitted to avoid redundancy.

The first thin film transistor **210** may include a first semiconductor layer **211**, a first gate electrode **213**, a first source electrode **215***a*, and a first drain electrode **215***b*, wherein the first semiconductor layer **211** may include amorphous silicon, polycrystalline silicon, an organic semiconductor material, or an oxide semiconductor material. The first gate electrode **213** may have various layered structures including various conductive materials, which are formed of, e.g., a Mo layer and an Al layer. Alternatively, the first gate electrode **213** may include a TiNx layer, an Al layer, and/or a Ti layer. The first source electrode **215***a* and the first drain electrode **215***b* may also have various layered structures including various conductive materials, which are formed of, e.g., a Ti layer, an Al layer, and/or a Cu layer.

In order to ensure an insulating property between the first semiconductor layer **211** and the first gate electrode **213**, a first gate insulating layer **121** including an inorganic material such as silicon oxide, silicon nitride, and/or silicon oxynitride may be between the first semiconductor layer **211** and the first gate electrode **213**. In addition, a first interlayer insulating layer **131** including an inorganic material such as silicon oxide, silicon nitride, and/or silicon oxynitride may be on the first gate electrode **213**. The first source electrode **215***a* and the first drain electrode **215***b* may be on the first interlayer insulating layer **131**. The insulating layer including the inorganic material may be formed through a chemical vapor deposition (CVD) or an atomic layer deposition (ALD) method. This will be also applied to exemplary embodiments and modifications thereof that will be described later.

A buffer layer **110** may be disposed between the first thin film transistor **210** and the lower substrate **100**. The buffer layer **110** may include an inorganic material such as silicon oxide, silicon nitride, and/or silicon oxynitride. The buffer layer **110** may improve the smoothness of an upper surface of the lower substrate **100**, or may prevent or reduce infiltration of impurities into the first semiconductor layer **211** of the first thin film transistor **210** from the lower substrate **100**.

In addition, a planarization layer **140** may be on the first thin film transistor **210**. For example, when an organic light-emitting device is on the first thin film transistor **210** as shown in FIG. **1**, the planarization layer **140** may planarize an upper portion of a protective layer covering the first thin film transistor **210**. The planarization layer **140** may include, for example, an organic material such as acryl, benzocyclobutene (BCB), hexamethyldisilioxane (HMDSO), etc. In FIG. **1**, the planarization layer **140** has a single-layered structure, but may be variously modified. For example, the planarization layer **140** may have a multi-layered structure.

A display device may be disposed on the planarization layer **140** of the lower substrate **100**. The organic light-emitting device as shown in FIG. **1** may be used as the display device. In the first pixel PX**1**, the organic light-emitting device may include, for example, the first pixel electrode **311**, an opposite electrode **305**, and an intermediate layer **303** between the first pixel electrode **311** and the opposite electrode **305**. For example, the intermediate layer **303** includes an emission layer. The first pixel electrode **311** is electrically connected to the first thin film transistor **210** by contacting one of the first source electrode **215***a* and the first drain electrode **215***b* via an opening formed in the planarization layer **140**, as shown in FIG. **1**. The second pixel PX**2** includes the second pixel electrode **321**, and the third pixel PX**3** includes the third pixel electrode **331**. Each of the first to third pixel electrodes **311** to **331** includes a light transmission conductive layer including a conductive oxide material such as ITO, In_2O_3, IZO, etc., and a reflective layer including metal such as Al, Ag, etc. For example, the first to third pixel electrodes **311** to **331** may each have a triple-layered structure including ITO/Ag/ITO.

The intermediate layer **303** including the emission layer may be integrally formed as a single body over the first to third pixel electrodes **311** to **331**, and the opposite electrode **305** on the intermediate layer **303** may be integrally formed as a single body over the first to third pixel electrodes **311** to **331**. The opposite electrode **305** may include a light transmission conductive layer including ITO, In_2O_3, IZO, etc., and may include a semi-transmissive layer including metal such as Al, Ag, etc. For example, the opposite electrode **305** may include a semi-transmissive layer including Mg, Ag, etc.

A pixel defining layer **150** may be on the planarization layer **140**. The pixel defining layer **150** includes an opening corresponding to each of the pixels, e.g., an opening exposing at least a central portion of each of the first to third pixel electrodes **311** to **331**, and thus, defines the pixels. Also, in the example of FIG. **1**, the pixel defining layer **150** increases the distance between an edge of each of the first to third pixel electrodes **311** to **331**, and the opposite electrode **305**, in order to prevent generation of an arc at the edge of the first to third pixel electrodes **311** to **331**. The pixel defining layer **150** may include, for example, an organic material such as polyimide, hexamethyldisiloxane (HMDSO), etc.

The intermediate layer **303** may include a low-molecular weight organic material or a polymer material. When the intermediate layer **303** includes a low-molecular weight material, the intermediate layer **303** may include a hole injection layer (HIL), a hole transport layer (HTL), an emission layer (EML), an electron transport layer (ETL), and an electron injection layer (EIL) in a single or multiple-layered structure and may be obtained by a vacuum deposition method. When the intermediate layer **303** includes a polymer material, the intermediate layer **303** may include an HTL and an EML. Here, the HTL may include PEDOT, and the EML may include a poly-phenylenevinylene (PPV)-based or polyfluorene-based polymer material. The intermediate layer **303** may be arranged by a screen printing method, an inkjet printing method, a deposition method, a laser induced thermal imaging (LITI) method, etc. However, the intermediate layer **303** is not limited thereto, but may have various structures.

The intermediate layer **303** may include a layer integrally formed as a single body over the first to third pixel electrodes **311** to **331** as described above, but alternatively, the intermediate layer **303** may include a layer patterned to correspond to each of the first to third pixel electrodes **311** to **331**. In either case, the intermediate layer **303** may include a first light emission layer. The first light emission layer may be integrally formed as a single body over the first to third pixel electrodes **311** to **331**, but alternatively, may be patterned to correspond to each of the first to third pixel electrodes **311** to **331**. The first light emission layer may emit light in a first wavelength band, e.g., light in a wavelength band from about 450 nm to about 495 nm.

The opposite electrode **305** is on the intermediate layer **303** to correspond to the first to third pixel electrodes **311** to **331**. The opposite electrode **305** may be integrally formed as a single body over a plurality of organic light-emitting devices.

As the organic light-emitting device may be easily damaged due to external moisture or oxygen, an encapsulation layer may cover the organic light-emitting device to protect the organic light-emitting device. The encapsulation layer may include a first inorganic encapsulation layer, an organic encapsulation layer, and a second inorganic encapsulation layer.

An upper substrate **400** is disposed above the lower substrate **100**, and the opposite electrode **305** may be between the upper substrate **400** and the lower substrate **100**. The upper substrate **400** may include a polymer resin. The upper substrate **400** may include, for example, a polymer resin such as polyethersulfone, polyacrylate, polyetherimide, polyethylene naphthalate, polyethylene terephthalate, polyphenylene sulfide, polyarylate, polyimide, polycarbonate, cellulose acetate propionate, etc. The upper substrate **400** may be variously modified. For example, the upper substrate **400** may have a multi-layered structure including at least two layers and a barrier layer between the at least two layers. The at least two layers may include the polymer resin. The barrier layer may include an inorganic material such as silicon oxide, silicon nitride, silicon oxynitride, etc. between the two layers. The upper substrate **400** may be flexible or bendable.

The upper substrate **400** may include first to third through holes **410**, **420**, and **430** respectively corresponding to the first to third pixel electrodes **311** to **331**. That the first to third through holes **410** to **430** correspond to the first to third pixel electrodes **311** to **331** denotes that the first through hole **410** overlaps the first pixel electrode **311**, the second through hole **420** overlaps the second pixel electrode **321**, and the third through hole **430** overlaps the third pixel electrode **331**, respectively, when viewed from a direction perpendicular to the upper substrate **400** (Z-axis direction).

An inner surface in each of the first to third through holes **410** to **430** of the upper substrate **400** is inclined with respect to a lower surface **400***b* of the upper substrate **400**. The cross-sectional area of each of the first to third through holes **410** to **430** is defined as a cross-sectional area taken along a virtual plane (XY plane) substantially parallel to the lower surface **400***b* of the upper substrate **400**. The cross-sectional area of each of the first through hole **410** to the third through hole **430** decreases in a direction from the lower surface **400***b* to an upper surface **400***a* of the upper substrate **400**. For example, a first cross-sectional area of each of the first through hole **410** to the third through hole **430** taken along a first virtual plane substantially parallel to the lower surface **400***b* of the upper substrate **400** is smaller than a second cross-sectional area of each of the first through hole **410** to the third through hole **430** taken along a second virtual plane substantially parallel to the lower surface **400***b* of the upper substrate **400** when the second virtual plane is closer to the lower surface **400***b* of the upper substrate **400** than the first virtual plane.

A reflective layer **403** is in each of the first to third through holes **410** to **430**. In detail, the reflective layer **403** is on the inner surface in each of the first to third through holes **410** to **430**. The reflective layer **403** may include metal having reflectivity such as Al, Ag, etc. The reflective layer **403** may not be only located in the first to third through holes **410** to **430**, but also may be on the lower surface **400***b* of the upper substrate **400**, the lower surface **400***b* facing the lower substrate **100**, as shown in FIG. **1**. In detail, the reflective layer **403** may cover a portion of the lower surface **400***b* of the upper substrate **400** outside the first to third through holes **410** to **430**.

A first color filter layer **413** is in the first through hole **410**. In addition, a second color filter layer **423** and a second quantum dot layer **425** are in the second through hole **420**, and a third color filter layer **433** and a third quantum dot layer **435** are in the third through hole **430**.

The first color filter layer **413** may only transmit the light of a wavelength within a range from about 450 nm to about 495 nm, the second color filter layer **423** may only transmit the light of a wavelength within a range from about 495 nm to about 570 nm, and the third color filter layer **433** may only transmit the light of a wavelength within a range from about 630 nm to about 780 nm. The first to third color filter layers **413** to **433** may reduce external light reflection in the display apparatus.

For example, when the external light is incident on the first color filter layer **413**, only the light of the predetermined wavelength as described above may pass through the first color filter layer **413** and the light of other wavelengths may be absorbed by the first color filter layer **413**. Therefore, in the external light incident into the display apparatus, only the light of the predetermined wavelength as described above may pass through the first color filter layer **413**, and some of the light passing through the first color filter layer **413** is reflected by the opposite electrode **305** or the first pixel electrode **311** under the first color filter layer **413** and emitted to the outside. Consequently, only some of the external light incident into the space where the first pixel PX**1** is positioned may be reflected to the outside, and thus, the external light reflection may be reduced. The above description may be also applied to the second color filter layer **423** and the third color filter layer **433**.

The second quantum dot layer **425** may convert light in the first wavelength band generated by the intermediate layer **303** on the second pixel electrode **321** into light in a second wavelength band. For example, when the intermediate layer **303** on the second pixel electrode **321** generates light of a wavelength within a range from about 450 nm to about 495 nm, the second quantum dot layer **425** may convert the light into the light of a wavelength within a range from about 495 nm to about 570 nm. Accordingly, the light of the wavelength within the range from about 495 nm to about 570 nm is emitted from the second pixel PX**2** to the outside via the upper substrate **400**.

The third quantum dot layer **435** may convert the light in the first wavelength band generated by the intermediate layer **303** on the third pixel electrode **331** into light in a third wavelength band. For example, when the light of a wavelength within the range from about 450 nm to about 495 nm is generated from the intermediate layer **303** of the third pixel electrode **331**, the third quantum dot layer **435** may convert the light into the light having a wavelength within the range from about 630 nm to about 780 nm. Accordingly, the light of the wavelength within the range from about 630 nm to about 780 nm is emitted from the third pixel PX**3** to the outside via the upper substrate **400**.

Each of the second quantum dot layer **425** and the third quantum dot layer **435** may have a structure, in which quantum dots are dispersed in a resin. The quantum dots may include a semiconductor material such as cadmium sulfide (CdS), cadmium telluride (CdTe), zinc sulfide (ZnS), indium phosphide (InP), etc. Each of the quantum dots may have a size of several nanometers, and the wavelength of the light after conversion may vary depending on the size of each of the quantum dots. The second quantum dot layer **425** and the third quantum dot layer **435** may include any type of resin capable of light transmittance. For example, a polymer resin such as acryl, benzocyclobutene (BCB), or hexamethyldisiloxane (HMDSO) may be used as a material for forming the second quantum dot layer **425** and the third quantum dot layer **435**.

The first pixel PX**1** emits the light of a first wavelength generated by the intermediate layer **303** to the outside without converting the wavelength. Therefore, the first pixel PX**1** does not include a quantum dot layer. As described above, because the quantum dot layer is not necessary in the first through hole **410**, a light transmission layer (i.e., a transparent layer) **415** including a light-transmitting resin is disposed in the first through hole **410**. The light transmission layer **415** may include acryl, benzocyclobutene (BCB), or hexamethyldisilioxane (HMDSO). Alternatively, the light transmission layer **415** may not be in the first through hole **410** unlike in the illustrated embodiment of FIG. **1**.

In the illustrated display apparatus, the light in first wavelength band is emitted to the outside from the first pixel PX**1**, the light in the second wavelength band is emitted to the outside from the second pixel PX**2**, and the light in the third wavelength band is emitted to the outside from the third pixel PX**3**. Therefore, the display apparatus may display full-color images.

During the manufacturing processes, the first to third through holes **410** to **430** are provided on the upper substrate **400**, and then, the first to third color filter layers **413** to **433** are positioned in the first to third through holes **410** to **430**. Therefore, mixing of the materials used during the processes of forming the first to third color filter layers **413** to **433** may be effectively prevented. For example, when the first color filter layer **413** is formed and the second color filter layer **423** is formed, the material used to form the first color filter layer **413** and the material used to form the second color filter layer **423** may be mixed on the substrate in the display apparatus according to the related art. However, in the display apparatus according to the illustrated exemplary embodiment, the first to third color filter layers **413** to **433** are in the first to third through holes **410** to **430**, and thus, mixing of the materials for forming the first to third color filter layers **413** to **433** may be prevented effectively.

In the display apparatus according to the related art, forming of a barrier layer on the substrate before forming the first and second color filter layers may be taken into account. The material for forming the first color filter layer and the material for forming the second color filter layer may not be mixed due to the barrier layer. However, in this case, in order to form the barrier layer to a sufficient height, a first barrier layer is formed and a second barrier layer has to be formed on the first barrier layer. Thus, processes may be complicated. In the display apparatus according to the illustrated exemplary embodiment, the process of forming the barrier layer during the manufacturing processes is obviated, and thus, the manufacturing processes may be simplified and a defect ratio may be decreased.

According to the display apparatus of the illustrated exemplary embodiment, the second quantum dot layer **425** and the third quantum dot layer **435** are in the second and third through holes **420** and **430** as described above. Therefore, the above descriptions about the first to third color filter layers **413** to **433** during the manufacturing processes may be also applied to the second and third quantum dot layers **425** and **435**. That is, in the display apparatus according to the illustrated exemplary embodiment, mixing of the materials used to form the second quantum dot layer **425** and the third quantum dot layer **435** during the manufacturing processes may be effectively prevented.

As a reference, the second quantum dot layer **425** is between the second color filter layer **423** and the opposite electrode **305**. Because the second color filter layer **423** transmits the light in the second wavelength band, the light in the first wavelength band generated by the intermediate layer **303** needs to be converted into the light in the second wavelength band by the second quantum dot layer **425** before being incident into the second color filter layer **423** that transmits the light in the second wavelength band. Likewise, the third quantum dot layer **435** is between the third color filter layer **433** and the opposite electrode **305**. Accordingly, an upper surface **413**_a_ of the first color filter layer **413**, which is opposite to the direction towards the lower substrate **100** (e.g., the negative Z axis direction), an upper surface **423**_a_ of the second color filter layer **423** in an opposite direction to the lower substrate **100** (e.g., the negative Z axis direction), and an upper surface **433**_a_ of the third color filter layer **433** in an opposite direction to the lower substrate **100** (e.g., the negative Z axis direction) may form continuous surfaces with the upper surface **400**_a_ of the upper substrate **400**, which is opposite to the direction towards the lower substrate **100** (e.g., the negative Z axis direction). For example, the upper surface **413**_a_ of the first color filter layer **413**, the upper surface **423**_a_ of the second color filter layer **423**, the upper surface **433**_a_ of the third color filter layer **433**, and the upper surface **400**_a_ of the upper substrate **400** may be substantially coplanar.

In addition, during the manufacturing processes or using the display apparatus after being manufactured, it may be necessary to prevent damage to the second and third quantum dot layers **425** and **435**. For example, an outgas generated from the second color filter layer **423** may damage the quantum dots in the second quantum dot layer **425** so that the quantum dots may not convert the light in the first wavelength band into the light in the second wavelength band. Likewise, an outgas generated from the third color filter layer **433** damages the quantum dots in the third quantum dot layer **435** so that the quantum dots may not convert the light in the first wavelength band into the light in the third wavelength band. Thus, it may be necessary to prevent the damages of the second and third quantum dot layers **425** and **435** from the outgas. To this end, a first protective layer **405** may be disposed between the second color filter layer **423** and the second quantum dot layer **425**, and between the third color filter layer **433** and the third quantum dot layer **435**. The first protective layer **405** may include an inorganic material such as silicon oxide, silicon nitride, or silicon oxynitride, such that the outgas may not pass through the first protective layer **405**. The first protective layer **405** may be integrally formed as a single body over the entire surface of the upper substrate **400**. Accordingly, the first protective layer **405** is between the first color filter layer **413** and the light transmission layer **415** in the first through hole **410** of the upper substrate **400**.

The first protective layer **405** includes an inorganic material, and thus may have a shape corresponding to a lower portion thereof when being formed. Accordingly, as shown in FIG. **1**, the first protective layer **405** is flat on a portion of the reflective layer **403** outside the first to third through holes **410** to **430** of the upper substrate **400**, and is formed along the reflective layer **403** in the first to third through holes **410** to **430** to be in contact with the first to third color filter layers **413** to **433**. Processes of forming the first protective layer **405** will be described later.

In addition, the intermediate layer **303** included in the organic light-emitting device is vulnerable to impurities such as external moisture or oxygen. Therefore, during the manufacturing or using the display apparatus after finishing the manufacturing, it is necessary to prevent outgas generated by the second and third quantum dot layers **425** and **435** from proceeding in a direction towards the intermediate layer **303**. To this end, a second protective layer **407** may be between the second quantum dot layer **425** and the opposite electrode **305** and between the third quantum dot layer **435** and the opposite electrode **305**. The second protective layer **407** may include an inorganic material such as silicon oxide, silicon nitride, or silicon oxynitride, such that the outgas may not pass through the second protective layer **407**. The second protective layer **407** may be integrally formed as a single body over the entire surface of the upper substrate **400**. Accordingly, the second protective layer **407** is in contact with the light transmission layer **415** in the first through hole **410** of the upper substrate **400**, is in contact with the second quantum dot layer **425** in the second through hole **420**, and is in contact with the third quantum dot layer **435** in the third through hole **430**. In addition, the second protective layer **407** is in contact with the first protective layer **405** on the portions in the lower surface **400**_b_ of the upper substrate **400**, the portions are outside the first through third through holes **410** to **430**.

FIGS. **2**A to **9** are cross-sectional views or plan views illustrating processes of manufacturing the display apparatus of FIG. **1**. In detail, FIGS. **2**A to **9** are cross-sectional views or plan views illustrating exemplary processes of manufacturing the upper substrate **400**, the first to third color filter layers **413** to **433**, the second quantum dot layer **425**, the third quantum dot layer **435**, the first protective layer **405**, and the second protective layer **407** in the display apparatus of FIG. **1**.

As shown in FIGS. **2**B and **3**, the upper substrate **400** including the first to third through holes **410** to **430** is prepared. Here, FIG. **2**B shows a cross-section of the display apparatus taken along line II-II of FIG. **3** which is a plan view.

Referring to FIG. **2**A, a layer **400_0** for forming the upper substrate **400** is prepared on a carrier substrate **10**. Further, referring to FIG. **2**B, the first to third through holes **410** to **430** are formed in the layer **400_0**. For example, a material for forming polyimide is applied onto the carrier substrate **10** by a slit coating method, etc. to obtain the layer **400_0**, and processes of exposing and developing certain portions by using a photomask are performed to form the first to third through holes **410** to **430** in the layer **400_0** on the carrier substrate **10**. After that, the material for forming polyimide is cured through a UV exposure, a thermal treatment, etc. to obtain the upper substrate **400** including the first to third through holes **410** to **430** as shown in FIGS. **2**B and **3**. The carrier substrate **10** may include, for example, a glass substrate.

The upper substrate **400** may be variously modified. For example, the upper substrate **400** may include other polymer resins than the polyimide, and may have a multi-layered structure including at least two layers and a barrier layer between the at least two layers. The at least two layers may include a polymer resin. The barrier layer may include an inorganic material such as silicon oxide, silicon nitride, silicon oxynitride, etc.

When the material for forming the upper substrate **400** such as polyimide has the same properties as those of a photoresist, the material is applied onto the carrier substrate **10** to form the layer **400_0** as described above, and after that, the processes of exposing and developing certain portions by using a photomask are performed to form the first to third through holes **410** to **430** in the layer **400_0** on the carrier substrate **10**. However, when the material for forming the upper substrate **400** does not have the same properties as those of the photoresist, a layer **400_0** is formed by using the material for forming the upper substrate **400** on the carrier substrate **10**, and after that, the first to third through holes **410** to **430** may be formed in the layer **400_0** by a wet etching method using the photoresist.

As the first to third through holes **410** and **430** are obtained through the processes such as the exposure, the development, etc., in any of the cases in which the material for forming the upper substrate **400** has characteristics of the photoresist and in which additional photoresist is used, an inner surface of each of the first to third through holes **410** to **430** is inclined with respect to the lower surface **400***b* of the upper substrate **400**. Accordingly, the reflective layer **403**, which is to be formed later, may be arranged on the inner surface of each of the first to third through holes **410** to **430** without causing a defect. Here, a cross-sectional area of each of the first to third through holes **410** to **430** taken along a virtual plane (XY plane) that is in substantially parallel with the lower surface **400***b* of the upper substrate **400** is reduced as approached from the lower surface **400***b* towards an upper surface **400***a* of the upper substrate **400**.

The upper substrate **400** may be formed by another method. For example, a layer **400_0** is formed on the carrier substrate **10** by using a material for forming the upper substrate **400**. After that, a laser beam is radiated to a certain portion in the layer **400_0** to obtain the upper substrate **400** including the first to third through holes **410** to **430**.

When the laser beam is radiated, the laser beam is not radiated to the layer **400_0** on the carrier substrate **10** by passing through the carrier substrate **10**, but is directly radiated onto the layer **400_0** on the carrier substrate **10**. With reference to a coordinate axis shown in FIG. **2**B, the layer **400_0** for forming the upper substrate **400** is arranged on a surface of the carrier substrate **10**, the surface is in the negative Z axis direction, and a laser beam is radiated in the positive Z axis direction from a laser beam source located in the negative Z axis direction with respect to the layer **400_0**, and then, the laser beam may be directly radiated to the layer **400_0** on the carrier substrate **10**. As such, as shown in FIGS. **2**B and **3**, an area of a cross-section in each of the first to third through holes **410** to **430**, wherein the cross-section is taken along a virtual plane (XY plane) that is in substantially parallel with the lower surface **400***b* of the upper substrate **400**, may be gradually reduced as approached from the lower surface **400***b* towards the upper surface **400***a* of the upper substrate **400**.

In addition, as shown in FIG. **4**, the reflective layer **403** is formed on the inner surface in each of the first to third through holes **410** to **430** in the upper substrate **400**. For example, a metal layer is entirely formed on the lower surface **400***b* of the upper substrate **400** by a sputtering method, etc. Here, the metal layer is also on the carrier substrate **10** in each of the first to third through holes **410** to **430**. After that, the metal layer on the carrier substrate **10** in each of the first to third through holes **410** to **430** is removed to obtain the reflective layer **403** as shown in FIG. **4**.

Removing of the metal layer on the carrier substrate **10** in each of the first to third through holes **410** to **430** may be performed by using a dry etching method using the photoresist. For example, the photoresist is arranged on the metal layer that is entirely on the lower surface **400***b* of the upper substrate **400**, and then, exposure and developing processes are performed to remove only the photoresist on the metal layer on the carrier substrate **10** in each of the first to third through holes **410** to **430**. After that, the metal layer on the carrier substrate **10** in each of the first to third through holes **410** and **430** may be removed by the dry etching method. Here, the photoresist remaining on the reflective layer **403** is also removed.

As described above, because the inner surface in each of the first to third through holes **410** to **430** is inclined with respect to the lower surface **400***b* of the upper substrate **400**, the reflective layer **403** may be formed on the inner surface in each of the first to third through holes **410** to **430** of the upper substrate **400**.

When the inner surface in each of the first to third through holes **410** to **430** is substantially perpendicular to the lower surface **400***b* of the upper substrate **400**, a defect of not forming the metal layer on the inner surface in each of the first to third through holes **410** to **430** may occur when the metal layer is entirely formed on the lower surface **400***b* of the upper substrate **400**.

After that, as shown in FIG. **5**, the first color filter layer **413** in the first through hole **410**, the second color filter layer **423** in the second through hole **420**, and the third color filter layer **433** in the third through hole **430** are formed by an inkjet printing method. As the color filter layers are formed by the inkjet printing method, the amount of waste material generated when forming the color filter layers may be reduced. Moreover, as the first to third color filter layers **413** to **433** are respectively in the first to third through holes **410** to **430**, mixing of the materials that are used during the processes of forming the first to third color filter layers **413** to **433** may be effectively prevented.

In addition, the first protective layer **405** is formed by using the silicon oxide, silicon nitride, or silicon oxynitride, so as to correspond to the entire lower surface **400**b of the upper substrate **400**, as shown in FIG. **6**. Accordingly, the first protective layer **405** may be in contact with the reflective layer **403** on the inner surfaces of the first to third through holes **410** to **430**, as well as the first to third color filter layers **413** to **433**. Because the reflective layer **403** is also on the outer portions of the first to third through holes **410** to **430** in the lower surface **400**b of the upper substrate **400**, the first protective layer **405** is also in contact with the reflective layer **403** on the corresponding portions. The first protective layer **405** may be formed by a CVD method. Here, in order not to damage the first to third color filter layers **413** to **433** that are formed previously, a low temperature CVD method performed at the temperature of about 200° C. or less may be used.

After forming the first protective layer **405**, as shown in FIG. **7**, the second quantum dot layer **425** and the third quantum dot layer **435** are formed in the second and third through holes **420** and **430**. As the quantum dot layers are formed by the inkjet printing method, the amount of waste material generated when forming the quantum dot layers may be reduced. In addition, because the second and third quantum dot layers **425** and **435** are in the second and third through holes **420** and **430**, mixing of the materials that are used in the processes of forming the second and third quantum dot layers **425** and **435** may be effectively prevented. The light transmission layer **415** may be formed on the first protective layer **405** in the first through hole **410**, alternatively.

In addition, the second protective layer **407** is formed by using the silicon oxide, silicon nitride, or silicon oxynitride, so as to correspond to the entire lower surface **400**b of the upper substrate **400**, as shown in FIG. **8**. Accordingly, the second protective layer **407** may be in contact with the first protective layer **405** on the outside of the first to third through holes **410** to **430**, as well as the second and third quantum dot layers **425** and **435**. The second protective layer **407** may be formed by the CVD method. Here, in order not to damage the first to third color filter layers **413** to **433** and/or the second and third quantum dot layers **425** and **435** that are formed previously, the low temperature CVD method executed at a temperature of about 200° C. or less may be used.

As described above, after forming the upper substrate **400**, the first to third color filter layers **413** to **433**, the second quantum dot layer **425**, the third quantum dot layer **435**, the first protective layer **405**, and the second protective layer **407**, the upper substrate **400** and the lower substrate **100** are bonded to each other as shown in FIG. **9**. Before the above process, the first to third thin film transistors **210** to **230**, the first to third pixel electrodes **311** to **331**, the intermediate layer **303**, and the opposite electrode **305** are formed on the lower substrate **100** through separate processes. In addition, after bonding the upper substrate **400** to the lower substrate **100**, the carrier substrate **10** is removed from the upper substrate **400**, and then, the display apparatus shown in FIG. **1** is manufactured. Alternatively, the carrier substrate **10** may be removed before bonding the upper substrate **400** and the lower substrate **100** to each other, and then, the upper substrate **400** and the lower substrate **100** are bonded to each other.

Bonding of the lower substrate **100** and the upper substrate **400** may be effected by a sealant applied to an outer

portion of a display area to allow the lower substrate **100** and the upper substrate **400** to be bonded to each other. Alternatively, a filling material is located in a space between the lower substrate **100** and the upper substrate **400** as shown in FIGS. **1** and **9**, and then, the lower substrate **100** and the upper substrate **400** are bonded to each other via the filling material. In this case, the filling material is a light-transmitting filling material including a light-transmissive polymer resin such as polyimide, epoxy, etc.

In the above description, the reflective layer **403** is on the outer portions of the first to third through holes **410** to **430** on the lower surface **400**b of the upper substrate **400**, as well as on the inner surface in each of the first to third through holes **410** to **430** in the upper substrate **400**. However, one or more exemplary embodiments are not limited thereto. For example, as shown in FIG. **10**, which is a cross-sectional view of another exemplary embodiment of the display apparatus of FIG. **1**, the reflective layer **403** may be only on the inner surface in each of the first to third through holes **410** to **430** in the upper substrate **400**, and may not on the outer portions of the first to third through holes **410** to **430** on the lower surface **400**b of the upper substrate **400**. In this case, the first protective layer **405** is in contact with the lower surface **400**b of the upper substrate **400** on the outer portions of the first to third through holes **410** to **430**.

In addition, a surface of the second color filter layer **423** in the second through hole **420**, the surface facing the second quantum dot layer **425**, and a surface of the third color filter layer **433** in the third through hole **430**, the surface facing the third quantum dot layer **435**, may be substantially flat to be substantially parallel with the upper surface **400**a of the upper substrate **400**. This is because the second color filter layer **423** and the third color filter layer **433** are formed by the inkjet printing method, and thus the material for forming the second color filter layer **423** and the third color filter layer **433** is in a liquid state. The liquid is cured and/or baked during the manufacturing processes, the second and third color filter layers **423** and **433** are in solid state. Likewise, a surface of the first color filter layer **413**, the surface facing the opposite electrode **305**, is substantially flat to be substantially parallel with the upper surface **400**a of the upper substrate **400**.

The display apparatus having the organic light-emitting devices as display devices has been described, but the exemplary embodiments are not limited thereto. For example, in the structure shown in FIG. **1**, the display devices connected to the first to third thin film transistors **210**, **220**, and **230** may not include the organic light-emitting devices, but other light emitting devices. For example, instead of the first to third pixel electrodes **311**, **321**, and **331**, the intermediate layer **303**, and the opposite electrode **305**, a first light-emitting device may be connected to the first thin film transistor **210**, a second light-emitting device may be connected to the second thin film transistor **220**, and a third light-emitting device may be connected to the third thin film transistor **230**. Each of the first to third light-emitting devices may include a first light emission layer. The first light emission layer may emit light in the first wavelength band, e.g., light of a wavelength within the range from about 450 nm to about 495 nm.

In the display apparatus according to the above-described exemplary embodiment the first to third light-emitting devices in the display apparatus include the first to third pixel electrodes **311** to **331**, the opposite electrode **305** corresponding to the first to third pixel electrodes **311** to **331**, and the first light emission layers in the first to third light-emitting devices are disposed on the first to third pixel electrodes **311** to **331** to be between the first to third pixel electrodes **311** to **331** and the opposite electrode **305**. According to another exemplary embodiment, the first to third light-emitting devices may include a nano-LED. The nano-LED is a kind of LED and may have a size of several nanometers to tens of nanometers. A pixel of the display apparatus may include one nano-LED or a plurality of nano-LEDs having smaller sizes.

In addition, in the display apparatus according to the above exemplary embodiments and modified examples thereof, the upper substrate **400** may include an opaque material, i.e., the upper substrate **400** may be opaque. For example, the upper substrate **400** may include a black pigment such as carbon black or an opaque material. This may be implemented when the material for forming the upper substrate **400** applied onto the carrier substrate **10** includes the black pigment or the opaque material. Alternatively, when the material for forming the upper substrate **400** is applied to form a layer, the layer may include particles including black or opaque material. In this case, the upper substrate **400** may function as a black matrix, and thus, various effects such as preventing the visibility of displayed images from degrading due to the external light may be obtained.

According to principles and one or more exemplary embodiments of the invention, the display apparatus may have a low defect ratio during the manufacturing processes and consume less amount of material. However, the exemplary embodiments are not limited to the above effects.

Although certain exemplary embodiments and implementations have been described herein, other embodiments and modifications will be apparent from this description. Accordingly, the inventive concepts are not limited to such embodiments, but rather to the broader scope of the appended claims and various obvious modifications and equivalent arrangements as would be apparent to a person of ordinary skill in the art.

What is claimed is:

1. A display apparatus comprising:

a first substrate;

a first light-emitting device, a second light-emitting device, and a third light-emitting device disposed over the first substrate, each of the first to third light-emitting devices including a first light emission layer;

a second substrate disposed over the first substrate with the first to third light-emitting devices therebetween, the second substrate including a first through hole, a second through hole, and a third through hole overlapping the first to third light-emitting devices;

a reflective layer on an inner surface of each of the first to third through holes;

a first color filter layer in the first through hole;

a second color filter layer and a second quantum dot layer in the second through hole;

a third color filter layer and a third quantum dot layer in the third through hole;

a first protective layer between the second color filter layer and the second quantum dot layer and between the third color filter layer and the third quantum dot layer;

a second protective layer disposed between the second quantum dot layer and the second light-emitting device and between the third quantum dot layer and the third light-emitting device,

wherein the second protective layer is in contact with the first protective layer on a portion of a lower surface of the second substrate outside the first to third through holes, the lower surface facing the first substrate.

2. The display apparatus of claim **1**, wherein the first to third light-emitting devices comprise:

a first pixel electrode, a second pixel electrode, and a third pixel electrode; and

an opposite electrode overlapping the first to third pixel electrodes,

wherein the first light emission layer is disposed over the first to third pixel electrodes and interposed between the first to third pixel electrodes and the opposite electrode.

3. The display apparatus of claim **1**, wherein the first light emission layer is configured to emit light in a first wavelength band, the second quantum dot layer is configured to convert the light in the first wavelength band into light in a second wavelength band, and the third quantum dot layer is configured to convert the light in the first wavelength band into light in a third wavelength band.

4. The display apparatus of claim **1**, wherein the reflective layer covers a portion of the lower surface of the second substrate outside the first to third through holes.

5. The display apparatus of claim **1**, wherein the second quantum dot layer is between the second color filter layer and the second light-emitting device, and the third quantum dot layer is between the third color filter layer and the third light-emitting device.

6. The display apparatus of claim **5**, wherein the first substrate is a lower substrate, the second substrate is an upper substrate, and an upper surface of the first color filter layer, an upper surface of the second color filter layer, and an upper surface of the third color filter layer, form a substantially continuous surface with an upper surface of the upper substrate, the upper surface of the upper substrate being opposite to the lower substrate.

7. The display apparatus of claim **1**, wherein the first protective layer is integrally formed as a single body over substantially an entire surface of the second substrate.

8. The display apparatus of claim **1**, further comprising a light transmission layer in the first through hole interposed between the first color filter layer and the first light-emitting device.

9. The display apparatus of claim **8**, wherein the first protective layer is between the first color filter layer and the light transmission layer.

10. The display apparatus of claim **1**, wherein the second protective layer is integrally formed as a single body over substantially an entire surface of the second substrate.

11. The display apparatus of claim **1**, wherein the inner surface of each of the first to third through holes is inclined with respect to the lower surface of the second substrate.

12. The display apparatus of claim **1**, wherein a first cross-sectional area of each of the first to third through holes taken along a first plane substantially parallel to the lower surface of the second substrate is smaller than a second cross-sectional area of each of the first to third through holes taken along a second plane substantially parallel to the lower surface of the second substrate, the second plane being closer to the first substrate than the first plane.

13. The display apparatus of claim **1**, wherein the second substrate includes an opaque material.

14. The display apparatus of claim **1**, wherein the second substrate comprises a black pigment.

15. The display apparatus of claim 1, wherein the second substrate is opaque.

16. A method of manufacturing a display apparatus, the method comprising the steps:

forming a layer of a first substrate on a carrier substrate;

forming the first substrate by forming a first through hole, a second through hole, and a third through hole in the layer of the first substrate;

forming a reflective layer on the first substrate;

removing the reflective layer on the carrier substrate in the first to third through holes;

forming a first color filter layer in the first through hole;

forming a second color filter layer in the second through hole;

forming a third color filter layer in the third through hole;

forming a first quantum dot layer on the second color filter layer in the second through hole;

forming a second quantum dot layer on the third color filter layer in the third through hole;

forming a first protective layer between the second color filter layer and the second quantum dot layer and between the third color filter layer and the third quantum dot layer;

forming a first light-emitting device, a second light-emitting device, and a third light-emitting device over a second substrate, the first to third light-emitting devices including a first light emission layer;

aligning and bonding the first substrate and the second substrate to each other with the first to third light-emitting devices therebetween, wherein the first to third through holes overlap the first to third light-emitting devices; and

forming a second protective layer disposed between the second quantum dot layer and the second light-emitting device and between the third quantum dot layer and the third light-emitting device, such that the second protective layer is formed to be in contact with the first protective layer on a portion of a lower surface of the second substrate outside the first to third through holes, the lower surface facing the first substrate.

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